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(54) Title: METHOD AND SYSTEM FOR SIMULATING MEDICAL PROCEDURES INCLUDING VIRTUAL REALITY AND CONTROL METHOD AND SYSTEM FOR USE THEREIN

(57) Abstract

During an actual medical procedure, the actions of a medical instrument (16) are measured and recorded. These actions are generated on a member representative of the medical instrument to simulate the actual medical procedure. Forces acting upon the medical instrument (16) are sensed and simulated in the member using a force/tactile reflecting mechanism. The preferred embodiment uses virtual reality technology including image processing, three-dimensional graphics and display methods, simulated force/tactile reflection, head/hand movement, position sensing, and sound generation to provide an accurate simulation of endoscopic medical procedures.

METHOD AND SYSTEM FOR
SIMULATING MEDICAL PROCEDURES
INCLUDING VIRTUAL REALITY AND CONTROL
METHOD AND SYSTEM FOR USE THEREIN

Cross-Reference To Related Application

5

This application is a continuation-in-part of copending U.S. application Serial No. 984,324, filed December 2, 1992.

Technical Field

10

This invention relates to methods and systems for simulating medical procedures for training and for remote control.

Background Art

Laparoscopic surgery, a specific application
15   of endoscopic surgery, is performed by:

(1) making several small openings into the peritoneal cavity 10 of the body 12 as shown in Figure 1;

(2) insufflating with an inert gas, CO_2
20   (providing medium for adequate anatomical inspection);

(3) inserting a viewing scope 14 (laparo-scope) into one opening 10;

(4) inserting other surgical instruments 16 into the other openings (i.e. staplers, cutting/cauter-
25   izing instruments, etc.); and

(5) maneuvering and manipulating these instruments 16 on the basis of tactile feel and the

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visual information of the surgical site from the insert-
ed viewing scope 14 (usually displayed on a TV monitor).

5   Because the feel of the instruments 16 and the
imagery of the surgical site is restricted to a small
local area which is not directly visible, surgeons must
train extensively (usually on animals) prior to perform-
ing human procedures. This type of surgery is still
very much an art rather than science.

10   Endoscopic and laparoscopic intervention is
being fervently applied to procedures (such as cholecys-
tectomies, hernia repair, nephrectomies, appendectomies,
and numerous gynecological procedures) being praised for
fast patient recovery time and decreased hospital and
surgery costs. As new applications emerge, training
15   will play a crucial role in technological adoption. A
need exists for a training device which will facilitate
the transition from more traditional open procedures to
endoscopic procedures by fostering the surgical skill
necessary for the execution of efficient and complica-
20   tion-free procedures.

           U.S. Patent No. 5,149,270, issued to McKeown,
discloses an apparatus for practicing endoscopic surgi-
cal procedures. The apparatus has a cavity in which an
object simulating a human organ is mounted for perform-
25   ing a practice procedure. The cavity is closeable to
outside view, thereby forcing the individual practicing
the procedure to use and manipulate the instruments
relying only upon a viewing scope in an attempt to mimic
the actual diagnostic and operating conditions. This
30   configuration, by relying upon physical linkages and

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organ materials, lacks the versatility, robustness, and repeatability of a programmable simulation device.

International PCT application No. PCT/US92/02186, published 1 October 1992, discloses an automated surgical system and apparatus. An endoscopic instrument and a viewing scope are controlled remotely via a control mechanism in communication with the surgical instruments over a telecommunications link. This device, while directed toward the remote control of surgical instruments, does not address the necessity of force feedback for giving the remote user the feel of actual surgical procedures. Further, the device is directed toward remotely performing actual surgical procedures rather than simulated surgical procedures for the purposes of training.

Summary of the Invention

It is an object of the above invention to provide a method and system for simulating actual medical procedures.

A further object of the above invention is to provide a method for providing a virtual reality in response to a position and orientation of a member representative of a medical instrument.

Moreover, an object of the above invention is to provide a method and system for controlling a medical instrument.

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An additional object of the above invention is to provide a four-axis controller for a medical instrument.

5   In carrying out the above objects, the present invention provides a method for simulating actual medical procedures which utilize at least one medical instrument. According to the present invention, the actions of the medical instrument are measured during an actual medical procedure. These measured actions of the
10   medical instrument are generated on a member representative of the medical instrument so as to simulate the actual medical procedure.

           In carrying out the above objects, the present invention further provides a system for simulating
15   actual medical procedures which utilize at least one medical instrument. The system comprises means for measuring the actions of the medical instrument during an actual medical procedure. Means are also provided for generating the measured actions on a member repre-
20   sentative of the medical instrument whereby the actions of the member simulate the actual medical procedure.

           In carrying out the above objects, the present invention also provides a method for providing a virtual reality in response to a position and orientation of a
25   member representative of a medical instrument. An electrical signal is generated for each of a plurality of degrees of freedom of the member as a function of the position and orientation of the member in three-dimensional space. At least one virtual reality force field
30   is generated in response to the generated signals. A force signal is generated for each degree of freedom as

a function of the force field. A force on the member is generated for each force signal, thus providing the virtual reality.

In carrying out the above objects, the present invention additionally provides a method for controlling a medical instrument. The position and orientation of a member representative of the medical instrument is measured. Actions are generated on the medical instrument based upon the measured position and orientation of the member. The forces acting upon the medical instrument are measured. Forces are generated on the member based upon the measured forces acting upon the medical instrument.

In carrying out the above objects, the present invention also provides a system for controlling a medical instrument. The system comprises means for measuring the position and orientation of a member representative of the medical instrument. Means are provided to generate actions on the medical instrument based upon the measured position and orientation of the member. The system further comprises means for measuring the forces acting upon the medical instrument. Means are provided to generate forces on the member based upon the measured forces acting upon the medical instrument.

In carrying out the above objects, the present invention also provides a four-axis controller for a medical instrument. The system comprises a member representative of the medical instrument. A four-axis interface device, which is responsive to the position and orientation of the member, is secured to the member.

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Electrical signals representative of the position and orientation of the member are generated in the four-axis interface device. Means for actuating the medical instrument in response to the electrical signals are

5   included. Means for generating a force field based upon a force induced upon the medical instrument are provided. A force signal for each axis of the interface device is generated by further means, with the actuators responsive to these force signals to provide a force to

10   each axis of the interface device for reflecting a force on the medical instrument to the member.

Brief Description Of The Drawings

        FIGURE 1 shows the insertion of a scope and an instrument into a body during a laparoscopic medical

15   procedure;

        FIGURE 2 is a block diagram representation of the recording apparatus;

        FIGURE 3 depicts the systematic scanning of an anatomical feature to generate a complete imagery

20   record;

        FIGURE 4 is a block diagram representation of the virtual reality training/replay apparatus;

        FIGURE 5 is a block diagram representation of the incorporation of the recording apparatus with the

25   virtual reality training/replay apparatus;

FIGURE 6 is a block diagram representation of using the virtual reality replay system to provide a surgeon with preoperative imagery;

5   FIGURE 7 is a block diagram representation of using the virtual reality system in conjunction with robotic endoscopic medical equipment;

FIGURE 8 is a block diagram representation of the force/tactile subsystem control concept;

FIGURE 9 is a schematic representation of the
10   laparoscopic simulator; and

FIGURE 10 shows the four-axis force reflecting module within an opening in the laparoscopic simulator.

Best Mode For Carrying Out The Invention .

Described is a method and an apparatus which
15   uses Virtual Reality Technology including image process-
ing, three dimensional graphics and display methods,
simulated force/tactile reflection, programmed stereo-
phonic sound generation, head/hand movement and position
sensing to provide an accurate control or simulation of
20   medical procedures, specifically: endoscopic medical
procedures including, but not limited to, cholycystec-
tomies, vasectomies, bowel resections, inguinal and
bilateral hernia repairs, appendectomies, lymphadenecto-
mies, vagotomies, bronchial surgeries, hysterectomies,
25   nephrectomies, lysis of adhesions, tumor extraction,
knee arthroscopies, and abdominal explorations; micro-
surgery, i.e. viteoretinal, otologic, laryngeal and
stereotactic procedures; intubations, including neonatal

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procedures; and arterial and venous replacement and bypass methods used, for example, in treatment of innominate and subclavian occlusive disease.

5   The apparatus can be used to provide realistic simulations of patients on which to practice medical procedures for training and qualification purposes, to provide a means for trainees to see and feel actual (or simulated) surgeries, to display information from previously obtained medical diagnostics or image modali-
10   ties (CT data, PET data, MRI data, etc.) to the surgeon overlaid on current image information during the surgery, and to provide the man-machine interface for robotic surgery.

       The apparatus consists of a two or three
15   dimensional display device, a two or three dimensional sound device, a graphics/image processing engine and storage module capable of real-time medical image generation, and programmable tactile/force reflecting mechanisms which can generate the "feel" of medical
20   instruments and the interaction of these instruments with the anatomical simulation. The preferred embodiment of the invention is designed for simulating endoscopic medical procedures due to the minimally invasive nature of these techniques.

25   The preferred embodiment of this invention addresses the problems presented by the prior art by providing means for controlled, preprogrammable simulation of a medical procedure (using both active tactile feel and imagery) so that standardized practice and
30   qualification sessions can be performed by surgeons. The same embodiment can also be used to augment the data

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normally delivered to the surgeon in actual endoscopic surgery, and can provide surrogate feels and imagery to surgeon trainees from actual surgeries being performed by expert surgeons.

5   The basic medical procedure simulation system consists of two basic functions:
                (1) measuring and recording sights, sounds, and feels generated during actual surgery;
                (2) accurately playing back these recorded
10   sights, sounds, and feels and for using the recorded data to generate new information necessary to emulate the responses to alternative actions taken by a surgeon trainee.

                Turning now to Figure 2, the recording appara-
15   tus 20 that allows the critical events in a medical procedure to be measured and recorded during actual surgeries performed by expert surgeons is shown. Medical instruments 16 having pressure and position sensors 22 are connected to a data digitizer 24. The
20   pressure and position data from the digitizer 24 is recorded by a recording system 26 consisting of a computer and a storage subsystem. A viewing scope 14 having pressure and position sensors 28 is connected to an image digitizer/recorder 30. The image digitiz-
25   er/recorder 30 is also connected to the recording system 26. The recording system 26 can either compress and store digital image data or store analog video on a computer-controlled video cassette recorder (VCR). The non-image data is stored on digital disk or tape
30   storage. An accurate time base 32 is also connected to the recording subsystem 26 to provide time stamps for the instrument locations, forces or pressures, and

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actions such as trigger actuations during the specified
scope locations, forces (or pressures), and image data
captured during the operation. Each data item (force,
position, trigger action item or image captured) is time
5   stamped so that it is placed accurately into the time
sequence of events during surgery. The recording
apparatus 20 in Figure 2 can be directly connected to a
playback apparatus (in Figure 5) to provide immediate
feedback to a trainee.

10   To support the generation of data and images
to accommodate various user inputs, which will be
different than the mechanics implemented in the operat-
ing room and will differ from any particular surgery
performed, a systematic scanning of anatomical features
15   is performed. Figure 3 depicts the systematic scanning
of anatomical features using the scope 14 to generate a
complete imagery record of organ and tissue orientation
surrounding the site of medical simulation. This
supports generation of in-between data and interpolated
20   views based on recorded data.

The virtual reality training/replay apparatus
40 needed to playback the recorded data is incorporated
in Figure 4. This apparatus 40 generates the virtual
space which displays the time stamped and interpolated
25   data stored in the image and data storage system 42. A
virtual reality control computer 44 receives image and
non-image data from the image and data storage system
42. Position, orientation, and force data are processed
by the computer 44 and sent to the force/tactile pro-
30   grammed controller and hand/instrument tracking subsys-
tem 46. The force/tactile programmed controller and
hand/instrument tracking subsystem 46 is connected to a

tactile/force reflecting subject simulation mechanism 48 in order to provide force feedback.

The virtual reality control computer 44 obtains image data from the image and data storage system 42 based on the position and orientation of the instruments. The control computer 44 processes this data and relays it to an image warp processor 50. The image warping function 50 uses morphing, defined as the correspondence of two images through corresponding polygon patches, as the means for providing interpolated images from data collected during recording sessions. A 3D graphics generator 52 is also connected to the virtual reality control computer 44 in order to generate accurate three dimensional images of endoscopic instruments. A graphics overlay unit 54 is used to overlay the three dimensional images from the 3D graphics generator 52 on the morphed video derived imagery from the image warp processor 50. The output of the graphics overlay unit 54 is fed into a three dimensional display system 56.

An optional (denoted by the dashed lines) trainee head tracking system 58 can be connected to the virtual reality control computer 44 to provide information for the three dimensional display generation function to control generation of view dependent imagery assuming that the display system 56 is a head mounted system. Alternative embodiments for the display system 56 which use more conventional display technology, such as CRTs, might not require head tracking systems 58. However, future systems are expected to replace CRT viewing of endoscope-derived image data with head-mounted three-dimensional viewing. This viewing ar-

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rangement will require the head position sensing subsys-
tem 58.

The inclusion of a head position sensing
subsystem 58 also allows the incorporation of a three-
5   dimensional sound generation system 60.   The sound
generation system receives audio information from the
virtual reality control computer 44 and sends this
information to a sound system 62.   The use of sound
generation is also optional since it is not necessary in
10   simulating endoscopic procedures.

Figure 5 shows how the recording apparatus 20
in Figure 2 can be used to acquire image and manipula-
tion data 70 which is then used to compose simulation
data sets 72 for replay on the virtual reality replay
15   apparatus 40 from Figure 4.   An experienced surgeon 74
performs an actual endoscopic medical procedure using
endoscopic instruments 76.   The recording system 20 is
used to measure and record the sights, sounds, feels,
and actions occurring during the actual medical proce-
20   dure.   The sights, sounds, feels, and actions data are
stored in the measured data and image storage system 70.
Simulation data sets 72 are formed off-line from the
measured data 70 by a data composition system 78.   The
virtual reality training system 40 uses images and data
25   in the simulation database 72 to allow a trainee 80 to
explore this data.   The trainee 80 can view, hear, and
feel operations through manipulation and positioning of
the simulated instruments, or based on his head loca-
tion.   Images or data not in the simulation database 72
30   are generated through interpolation between images/data
items which are in the database 72 (interpolation

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between images is accomplished through morphing -- mapping predetermined image polygons between images).

Figure 5 also shows how the recording apparatus 20 can be used to pick-up data and imagery from an in-progress medical procedure for immediate replay on the virtual reality replay/training apparatus 40. In this mode, the virtual reality replay apparatus 40 immediately receives the output of the recording apparatus 20 via a communications channel 82. Therefore, the trainee 80 does not explore the input data and imagery through manipulation, but rather experiences the data stream. This data includes the virtual forces generated by the force/tactile subsystem and applied to the trainee's hands through the simulated instruments. Thus, the trainee 80 can gain intuitive understanding of the medical procedure, including the feelings, sights, and sounds of the operation, without the risks and possible complications associated with medical intervention.

Figure 6 shows how elements of the virtual reality replay system 40 can be used to provide the surgeon 90 with views of preoperative information and imagery 92, such as CT scans and MRI scans, to augment what is available now for endoscopic procedures (for instance, video imagery from the laparoscope). A surgeon 90 performs an actual medical procedure using endoscopic instruments 94. The recording system apparatus 20 is used to measure and record the actions and images in the instruments 94 during the procedure. The virtual reality training system 40 incorporates preoperative test data and images 92 with the output of the recording apparatus 20. The use of virtual reality

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display techniques allows metabolic and anatomical
structure graphics to be overlayed on the basic video
imagery now available to the surgeon 90 -- this is
especially valuable if we provide the surgeon 90 with a
5   three dimensional viewer (such as a head-mount three-
dimensional viewer) for graphically enhanced anatomical
information.

Figure 7 shows how the virtual reality systems
described already can also be used to provide feedback
10   from and control information to robotic endoscopic
medical equipment 100. A remote surgeon's 102 instru-
ments, viewing scope, and head position are measured and
recorded by the virtual reality training system 104.
This data is transmitted to the robotic endoscopic
15   surgery equipment 100 via a communications channel 106.
A local surgeon's 108 instrument, scope, and head
position is also measured and recorded by a second
virtual reality training system 110. The robotic
instruments are controlled to perform the actions of
20   either the remote surgeon 102 or the local surgeon 108
on the patient 112. The resulting sights, sounds,
actions, and feels are experienced by both the remote
surgeon 102 and the local surgeon 108. The virtual
reality concept described in this document provides the
25   means for sharing control of such robotic equipment 100
between several surgeons or trainees.

The most important subsystems in the virtual
reality replay apparatus are the force/tactile control-
ler 46 and the tactile/force reflecting mechanism 48.
30   These systems use force reflection information generated
from the simulation database (or model-base) to create
the feel of the medical instruments. Figure 8 shows a

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control concept for creating the feel of medical instru-
ments during a simulation. The hands 120 of a surgeon
or trainee grasp and move a member representative of an
instrument. The position of the instrument 122 is
5   determined and fed into a geometric model of an organ
124. The geometric model 124 includes data representing
the organ size, position, surface characteristics (in
terms of elasticity, resistance to searing, slipperi-
ness, etc.). Forces and torques are applied to the
10   surgeon's/trainee's ·hands 120 from a force/torque
subsystem 126 using data from the geometric model 124.
Thus, realistic feels are produced on the simulated
medical instrument representing instrument-to-organ
interaction forces based on the position of the instru-
15   ment.

An apparatus for simulating laparoscopic
medical procedures shown in Figure 9 uses the servo
systems concept described in Figure 8 to the provide
force-feedback control. The apparatus consists of a
20   box-like enclosure 130 which provides three openings 132
for insertion of instruments 134. When the instruments
134 are inserted they are clamped to four-axis devices
136 such as the force reflection mechanism 140 shown in
Figure 10. This mechanism 140 includes, in effect, a
25   small backdrivable robot which moves in 4 degrees of
freedom: 1 linear position (extension) and 3 attitudes
(roll, pitch, and yaw). This is accomplished by the
extension actuator 142, roll actuator 144, pitch actua-
tor 146, and yaw actuator 148. This mechanism 140 can
30   translate and provide forces/torques under programmed
control (generated by the modeling subsystem in Figure
8) which feel to the trainee like the interactions
characteristic of the actual medical· procedure. These

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four-axis actuation systems are reduced implementations
of universal force reflection mechanisms described in
co-pending application Serial No. 984,324, filed Decem-
ber 2, 1992.

5   In operation, each of the four-axis devices
136 generate a series of signals 139 representative of
the position and orientation of the corresponding
instrument 134. These signals are transmitted to a
controller 138 which generates a series of force com-
10   mands 137 which are returned to the four-axis devices
136 to provide force feedback on the corresponding
instrument 134.

The controller 138 may be a virtual reality
simulation of the environment of a medical procedure,
15   formed either artificially or based upon data collected
during an actual medical procedure. The controller 138
could also represent one or more slave devices which
respond to follow the actions of the instruments 134,
measure the forces acting on the slave device, and
20   transmit force commands 137 back to the four-axis
devices 136.

It should be noted that there are a variety of
different ways that the four-axis device could be
implemented. This device could read the position of a
25   user's hand by means of a laser tracking system and
feedback forces by urging the user's hand with jets of
air. In the preferred embodiment, however, the user's
hand will grip a member 134 representative of a medical
instrument or another medical tool.

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The specific four-axis device shown in Figure 10 is now examined in more detail. The position, orientation, velocity, and/or acceleration provided on the force reflective mechanism 140 by a member 134 is sensed and transmitted as a command to the simulation which implements a virtual reality force field. In turn, a force command is generated based on the force field value for the position, orientation, velocity, and/or acceleration of the member 134 given by the simulation. This force command is transmitted to force reflective mechanism 140. Force is then generated on the member 134 by the force reflective mechanism 140 using four small, brushless, DC servo motors. The four axis force-reflection output and four-axis orientation and position control provides the user with direct kinesthetic feedback from the virtual environment traversed. A queuing button (not shown) can be incorporated in order to actuate the instrument within the simulation or control.

The invention in its preferred embodiment is applicable to controlling a virtual or simulated medical environment. However, the invention is also well suited to the control of a remote or physical medical instrument. Further, the present invention is suited for application to any number of axes. For instance, a full six-axis interface could be used for simulating or controlling medical procedures.

While the best mode for carrying out the invention has been described in detail, those familiar with the art to which this invention relates will recognize various alternative designs and embodiments

for practicing the invention as defined by the following
claims.

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What Is Claimed Is:

1.   A method for simulating actual medical procedures, the actual medical procedure utilizing at least one medical instrument, the method comprising the steps of:
measuring the actions of the medical instrument during an actual medical procedure; and
generating the actions on a member representative of the medical instrument;
whereby generating the actions simulates the actual medical procedure.

2.   The method of claim 1 further comprising the step of recording the measured actions.

3.   The method of claim 2 wherein the step of generating the actions on the member is performed based upon the recorded actions.

4.   The method of claim 1 wherein the actual medical procedure includes endoscopic surgery utilizing a viewing scope capable of generating images.

5.   The method of claim 4 further comprising the step of displaying the generated images.

6.   The method of claim 5 further comprising the step of recording the images generated by the viewing scope wherein the step of displaying is performed based upon the generated images as recorded.

7.   The method of claim 4 wherein the actual medical procedure includes preoperative exploration with

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the viewing scope and wherein the medical instrument comprises the viewing scope.

8. The method of claim 5 further comprising the step of measuring supplemental information, wherein the step of displaying is performed in conjunction with the playback of the supplemental information.

9. The method of claim 8 wherein the supplemental information is audio information.

10. The method of claim 8 wherein the supplemental information is derived from medical diagnostic equipment.

11. The method of claim 6 wherein the step of displaying is performed based upon diagnostic information.

12. A system for simulating actual medical procedures, the actual medical procedure utilizing at least one medical instrument, the system comprising:
    measuring means for measuring the actions of the medical instrument during an actual medical procedure; and
    generating means operatively associated with the measuring means for generating the actions on a member representative of the medical instrument;
    whereby the actions of the member simulate the actual medical procedure.

13. The system of claim 12 further comprising recording means operatively associated with the measuring means for recording the measured actions.

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14.   The system of claim 13 wherein the generating means is operatively associated with the recording means and wherein the generation of the actions on the member is performed based upon the recorded actions.

15.   The system of claim 12 wherein the actual medical procedure includes endoscopic surgery utilizing a viewing scope capable of generating images.

16.   The system of claim 15 further comprising display means operatively associated with the viewing scope for displaying the images generated by the viewing scope.

17.   The system of claim 16 further comprising recording means operatively associated with the viewing scope and the display means for recording the generated images wherein the display of the generated images is performed based upon the recorded images.

18.   The system of claim 15 wherein the actual medical procedure includes preoperative exploration with the viewing scope and wherein the medical instrument comprises the viewing scope.

19.   The system of claim 16 further comprising supplemental information means, operatively associated with the display means, for measuring supplemental information, wherein the display of the generated images is performed in conjunction with the playback of the supplemental information.

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20.   The system of claim 19 wherein the
supplemental information means measures audio informa-
tion.

5   21.   The system of claim 20 wherein the
supplemental information means measures information from
medical diagnostic equipment.

22.   The system of claim 18 wherein the
display means further comprise means for displaying
10   diagnostic information.

23. A method for providing a virtual reality
in response to a position and orientation of a member
representative of a medical instrument, the method
15   comprising the steps of:
generating an electrical signal for each of a
plurality of degrees of freedom of the member as a
function of the position and orientation of the member
in three-dimensional space;
20   generating at least one virtual reality force
field in response to the generated electric signals;
generating a force signal for each degree of
freedom as a function of the force field; and
directing a force on the member for each force
25   signal, the generated forces providing the virtual
reality.

24.   The method of claim 23 wherein the
virtual reality force field is also generated in re-
sponse to information obtained from an actual medical
30   procedure.

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25.   The method of claim 23 wherein the virtual reality force field is also generated in response to information obtained during pre-medical diagnostic procedures.

5   26. The method of claim 23 wherein the generated forces are tactile forces.

27.   A method for controlling a medical instrument during a medical procedure, the method comprising the steps of:

10   measuring the position and orientation of a member representative of the medical instrument;

generating actions on the medical instrument based upon the measured position and orientation of the member;

15   measuring the forces acting upon the medical instrument; and

generating forces on the member based upon the measured forces on the medical instrument.

28.   The method of claim 27 wherein the step

20   of measuring the forces acting upon the medical instrument includes measuring torques acting upon the medical instrument.

29.   The method of claim 28 wherein the step of generating the forces on the member includes generat-

25   ing torques on the member.

30.   The method of claim 27 wherein the medical instrument includes an endoscopic medical viewing scope capable of generating images.

31. The method of claim 30 further comprising the step of displaying the generated images.

32. The method of claim 30 wherein the medical procedure includes preoperative exploration with
5   the viewing scope.

33. The method of claim 31 further comprising the step of measuring supplemental information, wherein the step of displaying is performed in conjunction with the playback of the supplemental information.

10   34. The method of claim 33 wherein the supplemental information is audio information.

35. The method of claim 33 wherein the supplemental information is derived from medical diag-
15   nostic equipment.

36. The method of claim 33 wherein the step of displaying is performed based upon diagnostic information.

37. The method of claim 27 further comprising
20   the step of actuating the medical instrument in response to a command input.

38. A system for controlling a medical instrument during a medical procedure, the system comprising:
25   first measuring means for measuring the position and orientation of a member representative of the medical instrument;

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first generating means operatively associated with the first measuring means for generating actions on the medical instrument based upon the measured position and orientation of the member;

5   second measuring means for measuring the forces acting upon the medical instrument; and

second generating means operatively associated with the second measuring means for generating forces on the member based upon the measured forces on the medical

10   instrument.

39. The system of claim 38 wherein the second measuring means includes means for measuring torques acting upon the medical instrument.

40. The system of claim 39 wherein the second

15   generating means includes means for generating torques on the member.

41. The system of claim 38 wherein the medical instrument includes an endoscopic medical viewing scope capable of generating images.

20   42. The system of claim 41 further comprising display means operatively associated with the viewing scope for displaying the generated images.

43. The system of claim 41 wherein the medical procedure includes preoperative exploration with

25   the viewing scope.

44. The system of claim 41 further comprising supplemental information means, operatively associated with the display means, for measuring supplemental

information, wherein the display of the generated images is performed in conjunction with the playback of the supplemental information.

45.   The system of claim 44 wherein the supplemental information means measures audio information.

46.   The system of claim 45 wherein the supplemental information means measures information from medical diagnostic equipment.

47.   The system of claim 43 wherein the display means further comprise means for displaying diagnostic information.

48.   The system of claim 38 further comprising actuation means operatively associated with the medical instrument for actuating the medical instrument in response to a command input.

49.   A system for providing four-axis control for a medical instrument comprising:
        a member representative of the medical instrument;
        a four-axis device securable to the member, the four-axis device being responsive to the position and orientation of the member to generate electrical signals representative of the position and orientation of the member, the four-axis device including an actuator for each axis of the device;
        means for actuating the medical instrument in response to the electrical signals;

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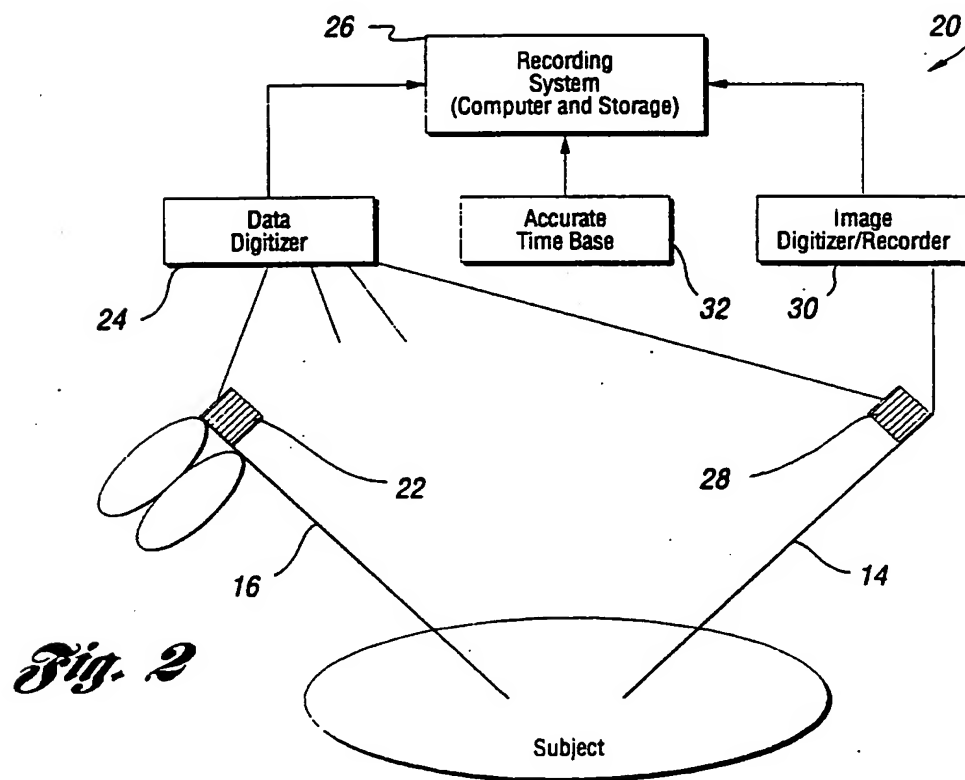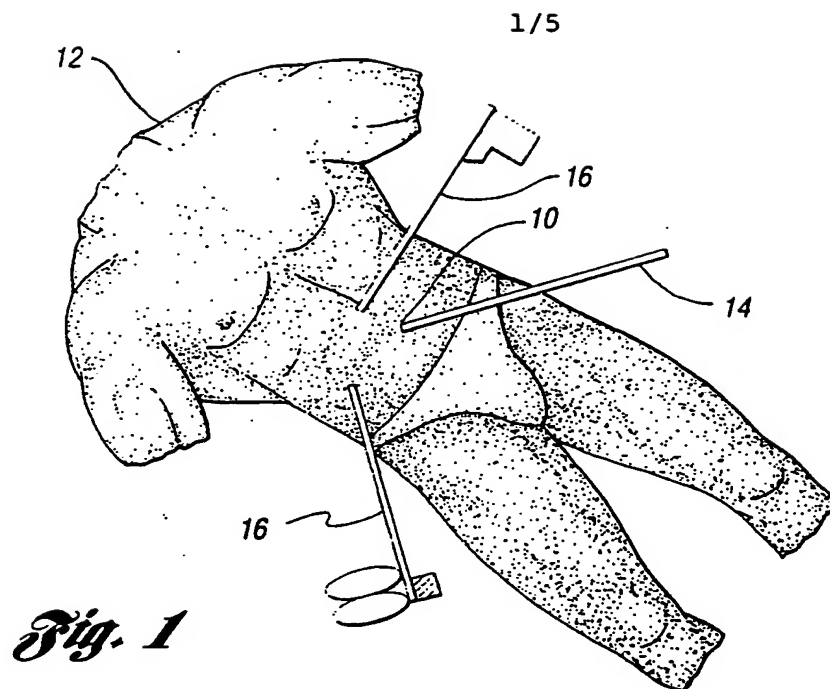means for generating a force field based upon a force induced upon the medical instrument; and

means for generating a force signal for each axis of the four-axis device as a function of the force
5   field, wherein the actuators are responsive to their respective force signals to provide a force to each axis of the four-axis device for reflecting the force on the medical instrument to the member;

whereby the position and orientation of the
10   member control the medical instrument.
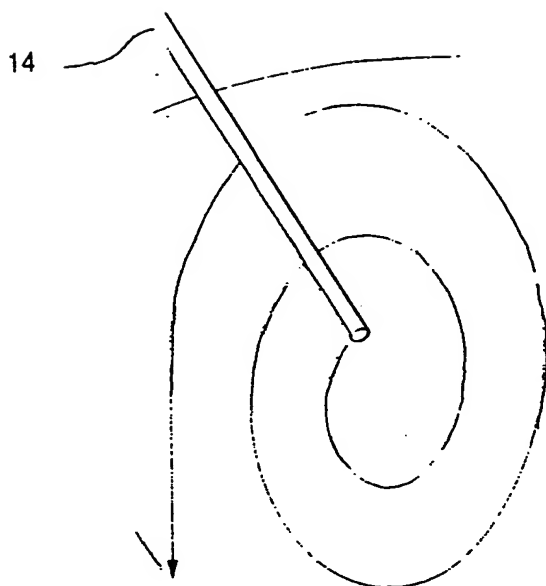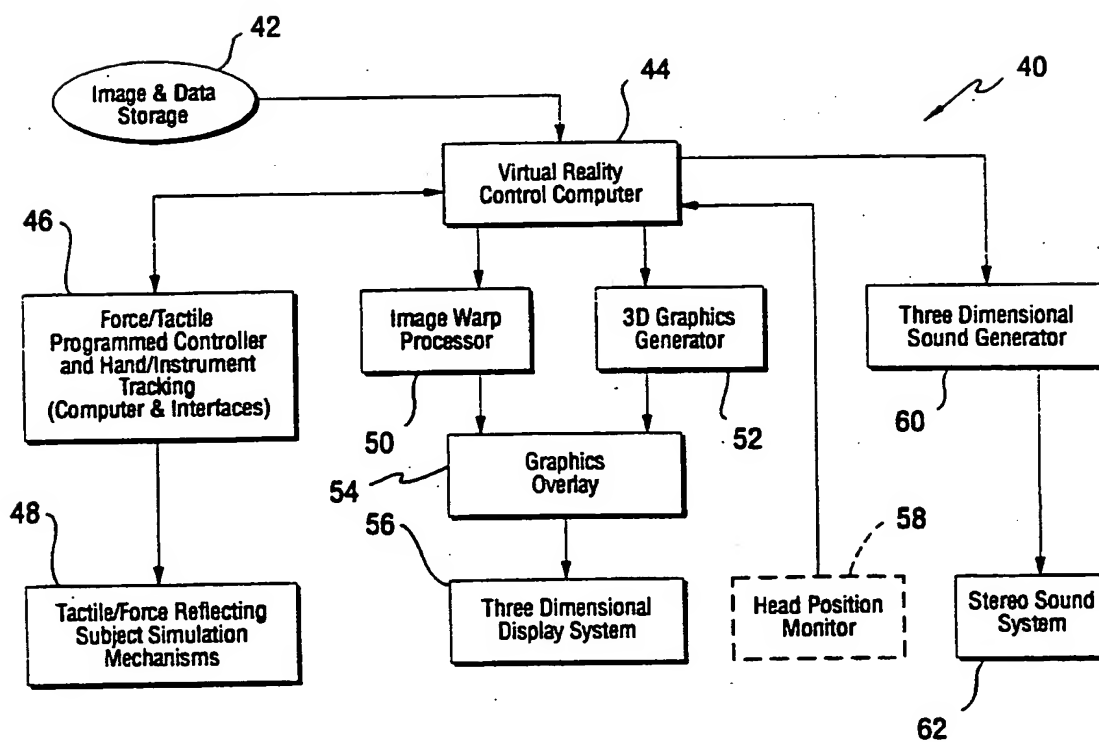

50.   The system of claim 49 wherein the four-axis device further comprises an encoder coupled to each actuator for generating the corresponding electrical signals.

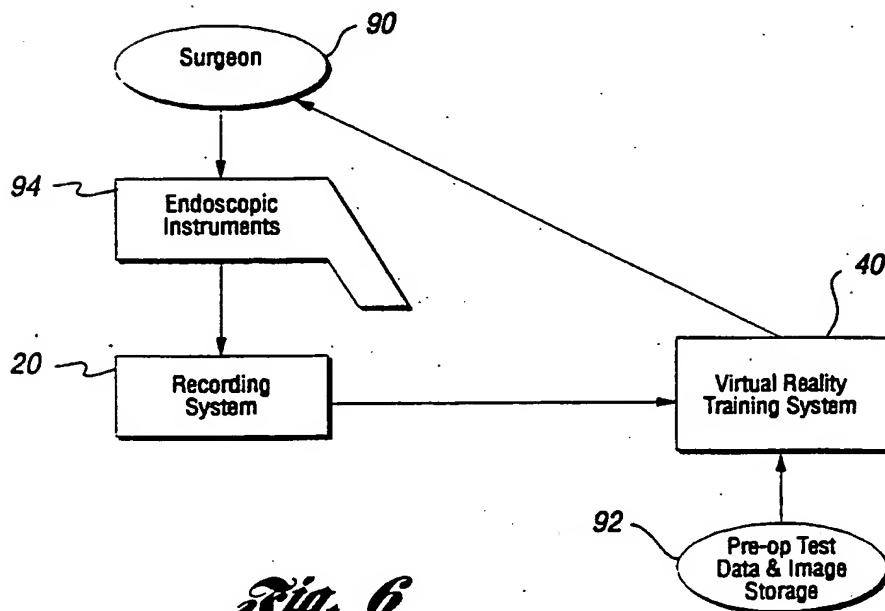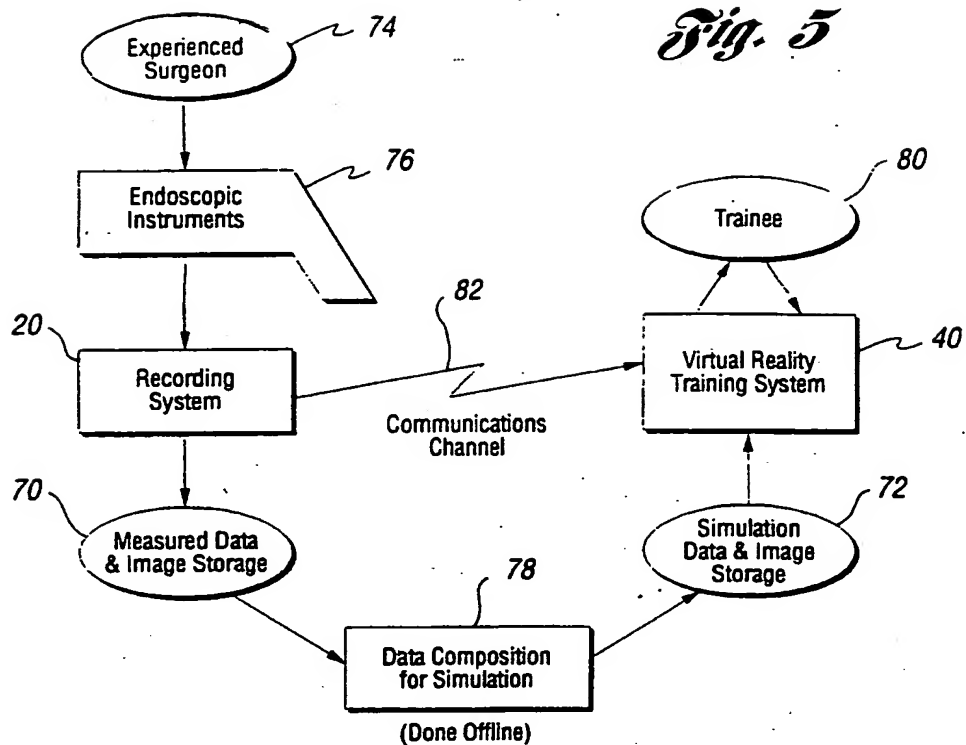15   51.   The system of claim 49 wherein the actuators are electric motors.

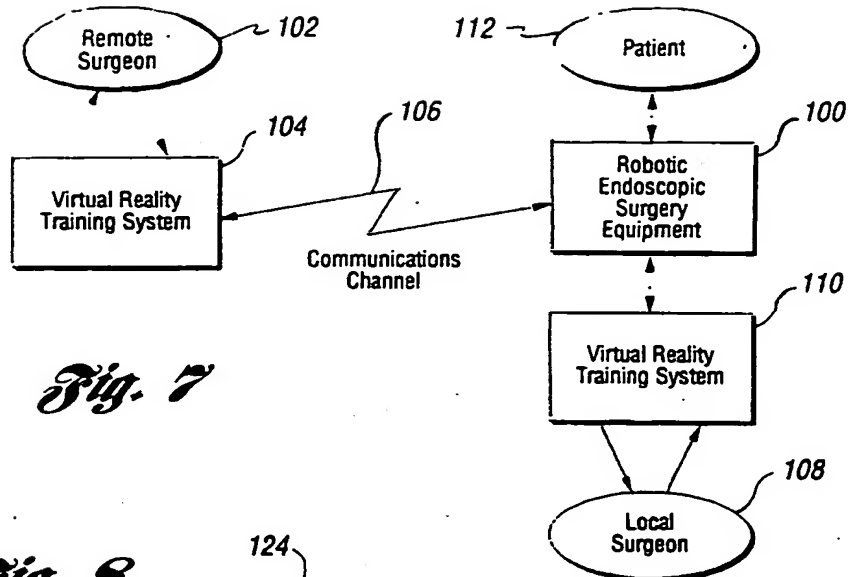52.   The system of claim 51 wherein the electric motors are back-drivable.

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Fig. 1

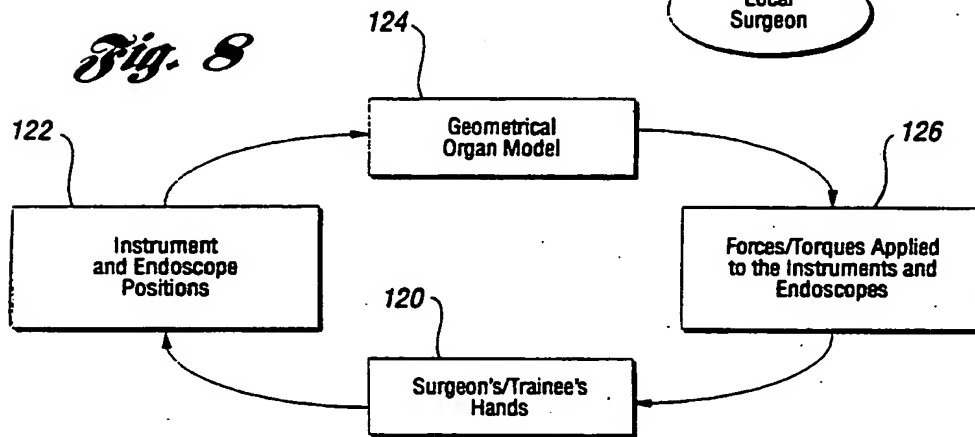
Fig. 2

Fig. 3

Fig. 4

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Fig. 5

```
  ⬭ Experienced        ⟋ 74
    Surgeon

       │
       ▼
  ▱ Endoscopic        ⟋ 76
    Instruments ─────────────┐
                             │
       │                     │
       ▼                     │
  ┌──────────┐        82     │
20 │ Recording│       ⟋       │
   │  System  │──────────────────────→ ┌──────────────┐        ⬭ Trainee      ⟋ 80
   └──────────┘       Communications   │Virtual Reality│ ⟋ 40      │
                        Channel        │Training System│←─────────
       │                               └──────────────┘
       ▼                                      ▲
70 ⬭ Measured Data                            │
   & Image Storage                     ⬭ Simulation    ⟋ 72
                                         Data & Image
       │              78                   Storage
       │             ⟋                     ▲
       └──→ ┌──────────────┐               │
            │Data Composition│──────────────┘
            │ for Simulation │
            └──────────────┘

              (Done Offline)
```
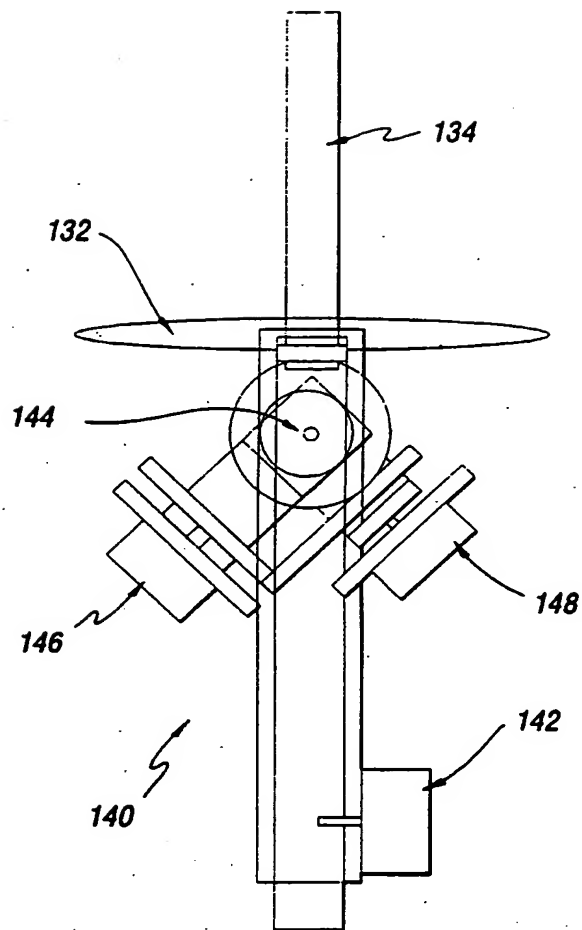
```
  ⬭ Surgeon          ⟋ 90
                                ▲
       │                        │
       ▼                        │
94 ▱ Endoscopic                 │
   Instruments ──────┐          │
                     │          │
       │             │          │
       ▼             │          │
   ┌──────────┐                 │    ⟋ 40
20 │ Recording│      ────────────→ ┌──────────────┐
   │  System  │──────────────────→ │Virtual Reality│
   └──────────┘                    │Training System│
                                   └──────────────┘
                                          ▲
                                          │
                        92 ⬭ Pre-op Test
                           Data & Image
                             Storage
```

Fig. 6

Remote Surgeon _102_

_104_

_106_

Virtual Reality Training System

Communications Channel

_112_ Patient

Robotic Endoscopic Surgery Equipment _100_

Virtual Reality Training System _110_

Local Surgeon _108_

Fig. 7

Fig. 8

_124_ Geometrical Organ Model

_122_ Instrument and Endoscope Positions

_126_ Forces/Torques Applied to the Instruments and Endoscopes

_120_ Surgeon's/Trainee's Hands

Fig. 9

_134_

_132_

_134_

_130_

_139_   _138_

_136_

_137_

Fig. 10

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   G09B23/28   A61B1/00   A61B19/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6   G09B   A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	GB,A,2 187 101 (NINAN,CHAMPIL ABRAHAM; US) 3 September 1987 see page 1, line 90 - page 4, line 82; claims 1-11	1-3, 12-15
A		23-25, 27,38

Y	DE,A,42 13 584 (OLYMPUS OPTICAL CO.) 5 November 1992	1-3, 12-15
A	see column 4, line 11 - column 14, line 24; claims 1-23; figures 1-21	4-7, 16-18, 23-25

	-/--	

[X] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 October 1994	1 7. 10. 94

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category°	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP,A,0 391 376 (DANON,NISSIM NEJAT; IL) 10 October 1990 see column 4, line 31 - column 19, line 4; claims 1,2,5,7-11,14-29	1-3, 12-15
A		4-7, 16-18, 27-32, 38-43, 49,51

P,Y	EP,A,0 571 827 (IBM) 1 December 1993 see column 5, line 18 - column 22, line 43; claims 1-26	1-3, 12-15

A	US,A,4 907 973 (HON,DAVID C.;US) 13 March 1990 see column 4, line 28 - column 15, line 34; claims 1-42	1-7

A	PEDERSEN,PEDER C. 'PROCCEEDINGS OF THE 12TH ANNUAL INTERNATIONAL CONFERENCE OF THE IEEE ENGINEERING IN MEDICINE AND BIOLOGY SOCIETY' 1 November 1990 , IEEE , PHILADELPHIA VOL.12,PART 1,MAZIER B. et al. "Computer Assisted Interventiopnist Imaging: Application to The Vertebral Column Surgery" pages 430-431 see the whole document	1,12,13, 27

A	WO,A,92 16141 (WILK,PETER J.;US) 1 October 1992 cited in the application see the whole document -----	1,27, 29-32, 37-43

1

INTERNATIONAL SEARCH REPORT

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		JP-A-	62170223	27-07-87
DE-A-4213584	05-11-92	JP-A-	4325147	13-11-92
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		CA-A-	2002919	14-05-90
		EP-A-	0426767	15-05-91
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		WO-A-	9005971	31-05-90
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		AU-A-	1675392	21-10-92